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National Aeronautics and Space Administration

SUIPR Report No. 706

July 1977

INSTITUTE FOR PLASMA RESEARCH
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The preparation of this report was supported by NASA Grant NGL 05-020-272.

SUMMARY

This *ad hoc* panel met in February 1977 to consider the needs of solar physics for space missions after the scheduled flight of Solar Maximum Mission in 1979. We were concerned only with scientific needs and opportunities. Neither budgetary implications nor payload feasibility were considered.

This report on the panel deliberations therefore makes suggestions only. We hope it will be a useful input to the more extensive and careful analysis of the appropriate committees, such as the Solar Physics Working Group. We have made no attempt to prioritize our proposed mission.

The following possible missions are describes briefly: A Solar Terrestrial Environment Mission; two versions of a Stereo Mission; a Large Scale Solar Structure Mission; a Solar Atmosphere Mission; a Solar Particle Acceleration Mission; and a Solar Pinhole Mission. We also append a brief account of the proposed Solar Probe Mission.

INTRODUCTION

This panel, the membership of which is shown on page 2, met in Boulder, Colorado on the afternoon of Saturday, February 26 and the morning of Sunday, February 27. Dr. Beckers was unable to participate in the meeting but added his comments subsequently. Dr. David Bohlin of NASA Headquarters attended as a guest.

The goal of this panel was to consider possible solar-related missions beyond Solar Maximum Mission, basing our discussions on the Parker Report. The results of our deliberations are summarized in the following pages. Each proposed mission is briefly specified, with a short description of the goals and a list of possible instruments.

Since our main aim was to generate ideas for consideration by our colleagues in the solar-physics community, we have made no attempt to prioritize the options.

The "Solar-Terrestrial Environmental Mission", described below, deserves some further comments. It represents a new, major program for coordinated solar and terrestrial measurements that can simultaneously perform pure research on solar structure and processes, and at the same time help determine the terrestrial consequences of the solar input. The complete program will require multiple spacecraft and would be able to utilize a manned space station most effectively.

After our meeting, it occurred to us that the lack of discussion of the Solar Probe concept was an unfortunate omission. Dr. Marcia Neugebauer kindly provided a short description of this mission, which is attached as an appendix.

COMPOSITION OF THE PANEL

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SOLAR TERRESTRIAL ENVIRONMENTAL MISSION

The purpose of this mission is to obtain data which will help in the understanding of solar influences on climate, weather and other environmental effects. It is essential that the spacecraft be flown over extended periods. They must therefore be free-flyers, each of which might be recovered and refurbished by a shuttle sortie. We believe that an optimum mission would comprise four spacecraft studying the sun, the interplanetary medium, the magnetosphere, and the surface and atmosphere of the earth.

SOLAR SPACECRAFT

This should be a free-flyer in near-earth orbit carrying the following instruments:

Total solar flux monitor

Solar spectrum monitor (IR to UV)

UV imaging instrument

X-ray imaging instrument

Hα imaging instrument

Magnetograph

White-light coronagraph and/or Lyman α coronagraph

Provision for accurate calibration is essential, and may require coordinated shuttle sorties. Provision for calibration by monitoring the flux of selected stars is also desirable.

INTERPLANETARY MEDIUM SPACECRAFT

This spacecraft should be in a highly eccentric orbit or possibly at the inner Lagrangian point to spend most of its time in the interplanetary medium. It should carry a complement of instruments to monitor the solar wind density, temperature, velocity, composition and magnetic field, and also high-energy particles.

MAGNETOSPHERIC SPACECRAFT

This should be a similar spacecraft, measuring the same quantities throughout the magnetosphere. (Possibly more than one spacecraft would be required.)

EARTH-SENSING SPACECRAFT

This should probably be a spacecraft in low-altitude polar orbit. This panel is not qualified to suggest appropriate instruments. However, it seems desirable that the instruments should be capable of monitoring surface conditions, as well as conditions in various layers of the atmosphere. Capability for monitoring thunderstorm activity and electric fields would be desirable.

STEREO I SOLAR MISSION

This mission would comprise a pair of spacecraft, one in near-earth orbit and the other in sun-centered orbit trailing the earth by 10° or more. A 10° interval would be convenient for optical stereoscopic viewing, but an interval of order 60° would give better resolution and would also give several days warning of the advent of new active regions. One of the Lagrangian points would therefore be an appropriate location. Such a mission could provide stereoscopic pictures of the sun's atmosphere which would facilitate far more complete understanding of the three-dimensional structure of the atmosphere, active regions, flare plasma, flare-related magnetic field structures, prominences, coronal transients, etc. We anticipate that such a mission would lead to a tremendous improvement in our understanding of the solar atmosphere and of solar activity since (apart from one radio mission) no 3-D solar measurements have previously been made.

If a spacecraft were 90° to the east of the sun, it would give several days warning of the advent of new active regions.

Such a mission might be flown in the 1983-87 time frame. (This is the anticipated period of declining solar activity, which is normally a time of major flares, and of solar minimum.) We envisage a much more complete set of instruments for solar research than is presently planned for the Out-of-Ecliptic Mission. The following seems a desirable complement of common instruments for both spacecraft:

A simple coronagraph (white light)

A simple x-ray imaging instrument

Radio receiver

Hard x-ray spectrometer

Particles and fields instrumentation for probe

A magnetograph is desirable but not of high priority. An IMP-type spacecraft should be in operation to provide particles and fields measurements near the earth.

STEREO II MISSION

This mission would be planned to provide information similar to that obtained by Stereo I, but fly at the time of solar maximum (1988-90) and carry improved instrumentation. Even more emphasis is placed on imaging for the precise determination of three-dimensional structure. Higher resolution will facilitate the study of small-scale atmospheric features. Both Stereo II spacecraft should carry the following instrumentation:

Coronagraph (white light)

Magnetograph

UV imaging instrument

Soft x-ray imaging instrument

Hard x-ray imaging instrument

Radio receivers

Particles and fields instrumentation

An IMP-type spacecraft should be in orbit to obtain particles and fields data concerning the near-earth solar wind.

A further advance in this concept would be the flight of three spacecraft: one in earth orbit, one 120° to the East of the earth, and one 120° to the West of the earth. This would for the first time provide continuous monitoring of the entire surface of the sun.

LARGE-SCALE SOLAR STRUCTURE MISSION

The aim of this mission is to study the large-scale structure of the sun to improve our understanding of large-scale convection, differential rotation, the dynamo process, the solar cycle and the large-scale behavior of active regions. It will be designed also to study the figure of the sun, relative to the oblateness question, and to make measurements relevant to the study of solar oscillations.

The spacecraft should be a free-flyer maintained in near-earth orbit for a period of years. We envisage the following complement of instruments:

Spectrograph (IR to UV) capable of determining Doppler shifts to 1m/s or better in an absolute frame of reference

Photospheric magnetograph with high spatial resolution for strong magnetic fields

Magnetograph with low spatial resolution to measure weak magnetic fields

Surface luminosity monitor

Figure-of-sun telescope to measure oblateness, etc.

In addition, a coronagraph would provide valuable information about the large-scale magnetic-field structure, and an x-ray telescope or XUV heliograph would provide information relevant to coronal holes. A solar flux monitor and a solar flux spectrometer would be valuable additional instruments, for instance in measuring possible fluctuations or oscillations in the solar temperature and luminosity.

ADDITIONAL SPACECRAFT

The aims of this mission would be furthered by the contemporanious flight of a near-sun probe such as a probe which could provide information concerning the gravitational multipole moments of the sun, in addition to other useful data. (Please see Appendix.)

SUNSPOT MISSION

The aim of this mission is to study the origin, evolution, structure and decay of sunspots and make related measurements of centers of activity. The optimum spacecraft would be a free-flyer in near-earth orbit but, since the prime instrument is the Solar Optical Telescope, the mission is highly appropriate to a Spacelab mission.

We envisage the following complement of instruments:

Solar Optical Telescope (optical and UV) with a complement of focal-plane instruments including a spectrograph (possibly based on Fourier transform spectroscopy if such an instrument is flight-proven). This instrumentation should provided capability for accurate mapping of magnetic fields.

(If the mission is assigned to a satellite, the telescope may be similar to the projected SOT but smaller in size.)

UV imaging (possibly of the SO-82A type)

UV, XUV spectrograph (possibly identical with the projected Spacelab facility)

Solar flux monitor

Solar flux spectrometer (These instruments may show if the "missing flux" due to sunspots results in a deficit in the flux or a spectral change in the flux.)

SOLAR ATMOSPHERE MISSION

The aim of this mission is to provide a long-term study of the dynamics and properties of the solar atmosphere. Detailed observations are best met by stereo missions, described elsewhere. However, short term limited observations could be obtained by means of a Spacelab mission designed in particular to study energy balance.

The following complement of instruments is envisaged:

- Solar Optical Telescope (optical and UV) with attachments capable of high resolution spectroscopy
- Soft x-ray telescope
- XUV facility instrument
- Coronal magnetograph (if possible)
- White light coronagraph (possibly also a Lyman α coronagraph)

The value of this mission would be greatly enhanced if it could be coordinated with a "Solar Probe" mission. (See Appendix.)

SOLAR PARTICLE ACCELERATION

The purpose of this mission is to study particle acceleration in solar active regions, especially in flares. A mission dedicated to this aim, which is flown in the descending phase of the coming solar cycle (1983-84), would take advantage of the occurrence of great flares during this phase and obtain significant information which will not be obtained by SMM.

The complement of instruments might be:

- Gamma-ray instrument (50 keV to 10 MeV, energy resolution of a few keV)
- High resolution hard x-ray imaging instrument (angular resolution 1 arc second, field of view $\geq$ 1 arc minute, energy range 10 - 150 keV)
- Low resolution hard x-ray imaging instrument (angular resolution 30 arc seconds, field of view 30 arc minutes, energy range 10 - 150 keV)
- X-ray polarimeter
- Photospheric magnetograph
- EUV magnetograph
- XUV spectroheliograph (SO-82A type) or soft x-ray telescope

A coronagraph would be advantageous. Such a mission should be supported by correlative plasma, particle and magnetic-field measurements made in the interplanetary medium by an IMP-type spacecraft.

SOLAR PINHOLE MISSION

The aim of this mission is to obtain high-resolution spatial information concerning gamma-ray and hard x-ray radiation from the sun. It should be applicable also to cosmic sources.

The mission appears to call for a probe in deep space. It would also be very appropriate for a space station.

The principal instrumental requirement is a large occulting sheet with suitable apertures (preferably variable) matched to an array of detectors on the spacecraft. These would be designed for

Gamma ray imaging,

X-ray imaging,

Possibly neutron imaging.

If possible, it would be desirable to mount a coronagraph on the spacecraft.

Such a facility, aimed at providing 1 arc second resolution, could be flown in the late 1980's as part of a Spacelab mission. This mission might be followed, possibly in the 1990's at or near solar maximum, by a larger facility aimed at higher spatial resolution. If at some time a space station is situated at a Lagrangian point, this would provide an excellent base for the receiver and for control of the aperture.

APPENDIX

A SOLAR PROBE MISSION

(provided by Marcia Neugebauer, J.P.L.)

Both the Jet Propulsion Laboratory and the European Space Agency have recently studied the feasibility and capabilities of a solar probe mission. The first studies assumed a Jupiter gravity assist tranjectory. The time from launch to Jupiter to perihelion would be 2.5 to 3.5 years. Any perihelion distance is possible -- even zero. Any inclination is also possible; an orbit perpendicular to the ecliptic would allow continuous viewing from the earth with no solar occultation near perihelion. If a thrusting maneuver is performed at perihelion, the aphelion could be lowered to perhaps 2 AU so that the spacecraft could return to the Sun in only a year. Studies are now underway to determine the feasibility of using a solar sail propulsion system (rather than Jupiter gravity assist) to obtain a less eccentric orbit with aphelion inside 1 AU.

Conventional thermal control technology allows survival of the spacecraft to approximately 4 solar radii. Even closer approaches may be possible with active cooling. Telecommunication is the principal source of concern. It may be necessary to go to higher frequencies than those currently used for radio systems on deep space missions.

There are three different levels of complexity under consideration for the scientific investigations to be carried out by a solar probe: (1) a very simple spacecraft performing only radio transmission experiments, (2) a simple fields and particles payload, and (3) a complex set of instruments which includes imaging and a hydrogen maser.

Much can be learned solely through the analysis of the radio signals transmitted to and from the spacecraft. Probably the most important of these radio experiments is the determination of the gravitational quadrupole moment of the Sun, J_2, which is related to the internal density distribution and rotation of the Sun. These parameters are crucial to theories of solar and stellar evolution. By making the spacecraft drag-free, the accuracy is expected to be sufficient to detect the minimum likely value of J_2, which is that associated with internal rotation at the observed surface rate. The solar probe would be able to improve considerably the measurement of the gravitational constants β and γ, which are both equal to unity in Einstein's theory but have different values in other gravitational theories.

Several outstanding questions in coronal physics could be answered by a complement of fields and particles experiments on a solar probe: (1) Does the solar wind come from all over the Sun or only from open field regions? (2) Which is the more important method of acceleration of the solar wind: inhibition of conduction or the addition of energy by wave damping? These two processes should give very different temperature profiles close to the Sun. (3) What is responsible for the puzzling helium observations? What type of solar regions have high helium concentration and what type have low? Where and how do the helium ions acquire a greater flow velocity and higher temperature than the hydrogen? (4) Does the solar wind flow ever become turbulent as suggested by radio observations? (5) To what distance from the Sun does the solar wind corotate with the Sun and what is the total rate of angular momentum loss by the Sun? (6) Are energetic solar particles continuously accelerated throughout interplanetary space or does most of the acceleration occur close to the Sun? (7) Are energetic particles stored in close field regions close to the Sun? (8) Do energetic particles cause flares?

Stepping up in complexity, we can conceive of high-resolution telescopes capable of discovering and studying the solar fine structure hinted at by ground-based observations. Finally, if a hydrogen maser were carried, it would be possible to test the second-order terms in the equations for the general relativistic red shift, the dragging of inertial frames by the rotating Sun, and a possible anisotropy in the global speed of light.